ON CERTAIN ELECTRICAL PROCESSES IN THE HUMAN BODY AND THEIR RELATION TO EMOTIONAL REACTIONS

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ON CERTAIN ELECTRICAL PROCESSES IN THE HUMAN BODY AND THEIR RELATION TO EMOTIONAL REACTIONS

I. PHYSICAL AND PHYSIOLOGICAL

THIS report[1] deals with experiments conducted to develop the best available method of applying the so-called "psycho-galvanic reflex" to the study of the emotional reactions both in normal individuals and various forms of psychoses. The work is divided into three parts, as follows: (1) the investigation of the physiological causes of the galvanometric deflections; (2) the study of sources of error in their use arising from physical causes, and of the methods of eliminating them; (3) the testing of the value of the deflections as indicators of emotion by statistical comparison with the introspective estimates; and supplementarily, the application of the method of inquiry to the study of nervous and mental disorders.

Most of the time at our disposal was devoted to the first three portions of the problem, and the few experiments with patients were carried on rather with a view to testing the methods of application than with the hope of securing any notable psychological information.

The apparatus at the beginning of the experiments consisted of (*a*) a Leeds and Northrup, Type H, D'Arsonval galvanometer, sensitivity 38×10^{-10} ampères, (*b*) the Ayrton shunt, (*c*) non-polarizable electrodes of the calomel type, (*d*) the Gordon cell, where an outside current is used. The deflections are read direct from a millimeter scale, 2 m. distant from the galvanometer mirror.[2] The elec-

[1] The material here presented was collected almost entirely during the time between October 1 and December 1, 1909. For this reason the observations consist largely of single experiments, which seem to the writers, however, to reflect with comparative accuracy the properties of the method under consideration. In view of present conditions in the problem, their publication seems justified; cf. Dunlap, *Psych. Bull.*, VII., 174–177, also Sidis' reply, *Psych. Bull.*, VII., 321–322. The second named writer is mainly responsible for the work up to p. 26 and from this point the first named.

[2] Values are uniformly given in terms of mm. deflections. With the galvanometer at full sensibility, the current is 19×10^{-10} ampère per mm. of deflection; when cell-current is used, the current is 1900×10^{-10} ampère per mm. of deflection unless otherwise specified.

trodes were constructed of glass tubes shaped like ordinary test tubes, 3 cm. inside diameter, 15 cm. long, with the conducting wires sealed in the bottom point of each. These were fitted into holes in a pair of horizontal boards on each side of a massage table. The subject reclined on this table with the hands strapped to the boards, palms down, with the middle finger protruding downward in the holes, each being immersed in the fluid to a depth of between 4 and 5 cm. The straps were drawn tight enough to limit the motions of the hands to a small range. Moreover, the position was comfortable and there was no tendency to move the hands during the experiments. The depth of immersion, therefore, remained practically constant and with it such changes of resistance as would be caused by a change in the area of the surface immersed or by a change in the length or shape of the conducting column of fluid. In some of the first experiments, funnels with saturated cotton were inserted in the tubes; the hands were strapped down with the palms in contact with the cotton. Evaporation caused such changes in resistance that this method was soon abandoned for that of immersing the fingers. With the subject and apparatus thus arranged, a large number of experiments were carried on in which the subject responded in the usual manner to a series of association words and after a short interval graded the feeling aroused as (A) strongly emotional, (B) rather emotional, (C) rather unemotional, (F) practically devoid of emotional reaction. With this form of experiment as the basis of our method, a variety of studies were carried on to learn the sources of error psychical and physical in its use, and to modify the procedure and apparatus accordingly.

Before describing the experiments, it may be well to mention some of the disadvantages in other forms of apparatus which led to the adoption of that which is described above. Dry metal plates, which have been used in many experiments, have the serious objection that changes in pressure or in area of the surface in contact produce marked changes in the deflections, thereby confusing the picture. The use of copper plates in a strong electrolyte has the disadvantage of introducing an electromotive force greater than that produced by the body. The result of this is that in studying the causation of deflections, one is handicapped in the effort to discriminate between changes in body resistance and changes in electromotive difference of potential developed by the body. Calomel electrodes are relatively non-polarizable and with them it is often possible to conduct an experiment without the development of a difference of potential between the two electrodes greater than .0001 volt, while the difference of potential between the two hands varies from

0 to .006 volt. These values are easily calculated by measuring the resistance of the body with a current of known voltage and by proper interpretation of other observations noted below.

There has been much discussion about the nature of the physiological processes involved in the psycho-galvanic reflex. Physically, the chief point under discussion is whether the galvanometric deflections are caused by changes in electrical difference of potential or in body resistance. Physiologically, the question is of what organs are the seat of the phenomena. Peterson and Jung discuss these questions as follows:[3]

"So far as has yet been determined, it would seem that the sweat glandular system is the chief factor in the production of this electric phenomenon, inducing on the one hand under the influence of nervous irritation a measurable current or, on the other hand, altering the conductivity of the body. Since water contact excludes changes induced by pressure on metal electrodes, and blanching of the fingers by the Esmarch bandage excludes changes in connection with the blood supply, both of these factors play but a small part in the deviations of the galvanometer. Change in resistance is brought about either by saturation of the epidermis with sweat, or by simple filling of the sweat-gland canals or perhaps also by intracellular stimulation; or all of these factors may be associated. The path for the centrifugal stimulation in the sweat-gland system would seem to lie in the sympathetic nervous system. These conclusions are based upon facts at present at hand and are by no means felt to be conclusive."

Sidis and Kalmus claim to have proved that the deflections are caused by changes in potential developed within the body and to have excluded resistance changes and sweat-gland activity from playing any part.

The various possible physiological explanations may be enumerated as follows: Changes of electrical potential may be caused by "action currents" emanating from voluntary muscles, from the smooth muscles of the blood vessels, from nerve trunks, or from sweat-glands. They might also be caused by electro-chemical action between the sweat and the electrolyte in the electrodes. They might be caused by thermo-electric phenomena at surfaces of contact between electrically different substances within the tissues or at the point of contact between the tissues and the electrolyte. Resistance changes might be caused by vaso-dilation or vaso-constriction or by sweat-gland activity. In the latter case, they might result from change in the glandular tissue or from filling and distention of the sweat tubules.

[3] *Brain*, XXX., p. 158.

The assertion by Sidis and Kalmus that resistance changes have been excluded is based on the following experiments and reasoning. "Hypodermic needles were inserted well under the skin until blood flowed freely. The hands, with the needles in position, were placed within the liquid electrodes." After establishing this connection between the body fluids and the electrolyte, and thus eliminating skin resistance, deflections were obtained similar to those without needles. This is said to prove that changes in skin resistance do not cause the deflections. Body (subcutaneous) resistance within the skin is said to be ruled out as follows: "Heating and cooling the arms put in an Esmarch bandage so as to exclude circulatory variations brought about galvanometric deflections. The experiments with hot and cold applications gave but slight variations, insufficient to account for the galvanometric phenomena observed under the influence of emotional states. The variations due to raising the temperature did not differ from those due to lowering the temperature. Furthermore, after a minute or two of continuous cooling or heating the arms, the reading was the same as that before the temperature changed. The hot and cold applications acted, therefore, in the nature of mere temperature stimulations." From this it is argued that the deflections are not traceable to resistance changes resulting from heating of the body. Esmarch bandages were used to exclude circulatory changes and deflections still followed the use of stimuli. The conclusions are summed up as follows: "Our experiments go to prove that the causation of the galvanometric phenomena can not be referred to skin resistance, nor can it be referred to variations in temperature, nor to circulatory changes with possible changes in the concentration of the body-fluids. Since the electrical resistance of a given body depends on two factors—temperature and concentration—the elimination of both factors in the present case excludes body resistance as the cause of the deflections. Our experiments, therefore, prove unmistakably that the galvanic phenomena due to mental and physiological processes can not be referred to variations in resistance, whether of skin or body. Resistance being excluded, the galvanometric deflections can only be due to variations in electro-motive force of the body."

The evidence does not seem to be conclusive. The fact that when skin resistance is eliminated by the use of needles deflections still occur, shows that under those conditions change in skin resistance is not the sole cause of deflections, but it does not exclude it as a contributing cause, nor under other conditions, as the main cause. The conclusion that heating and cooling the arms merely acted as thermal stimuli is doubtless correct, but it does not follow that the

deflections are independent of thermal changes in the body; for owing to the great insulating power of the subcutaneous fat and the rapid circulation of the blood, it is doubtful if the body fluids were perceptibly heated or cooled in this experiment.

In the present experiments, the relative influence of potential and resistance changes in causing deflections was studied by use of two separate methods. One was to connect the galvanometer with electrodes as nearly isopotential as possible and insert the fingers in these. The other was to connect the body and galvanometer in series with a Gordon cell of known voltage. For the first method, the various electrode tubes which had been prepared were connected with the galvanometer in pairs to show their relative potentials. This was done as follows: the wires leading from the two electrodes to be tested were connected with the two poles of the galvanometer. The ray of light from the galvanometer mirror was brought to the zero point in the middle of the scale, before the circuit was closed. Two limbs of a Y-shaped tube were then introduced into the two tubes and the electrolyte sucked up far enough to establish a fluid connection between the electrodes. With all but one of the pairs thus tried, the galvanometric deflection was over 400 mm. With the remaining pair (nos. 2 and 3) the deflection was + 50 mm. at the beginning of the experiment, and after testing each with each of the other tubes, it was — 92 mm., the change being probably the result of polarization. This pair of electrodes was used exclusively in all our first series of experiments dealing with body currents. The difference of potential between these two electrodes, which is indicated by a deflection of 50 mm., was estimated as follows: the current is 95×10^{-9} amp., and the resistance of a similar pair of electrode-tubes and the column of fluid connecting them was found with the aid of the Gordon cell to be about 1,060 ohms, to which must be added the resistance of the galvanometer, 520 ohms. By Ohm's law the electromotive difference of potential is approximately .00015 volt. This is then the difference of potential which existed between electrodes 2 and 3 at the time of this test. The current was not driven through tubes 2 and 3 for fear of polarization, but all the tubes were the same size and shape and the fluid in them of the same concentration. Their resistance was therefore approximately equal. Immediately after this difference of potential was tested the Y-tube was removed and the subject inserted the middle finger of his right hand in electrode 2 and that of his left in 3. Thus the circuit consisted of the body connected in series with the galvanometer through the two electrodes. After a series of experiments in muscular contractions, the galvanometer reading was

— 300 mm. The fingers were then reversed with respect to the tubes and the reading was then + 300. At other times similar results were obtained, as, for instance,—reading with fluid connection between electrodes — 240, reading with fingers in first position + 55, in reversed position — 98. In these experiments the fact that reversal of the fingers gives a reversal of the deflection shows that there is a difference of potential between the fingers generated in the body which is greater than that which exists between the two electrodes; and where the deflections in the two directions are approximately equal, the body potential is much greater.

The ratio between the two may be calculated as follows: The point on the scale midway between the positive and negative deflections may be assumed to be the value which the deflection would have if the electrode potential alone were acting through the resistance of the body. The ratio between the electrode potential and the body potential is equal to that between this hypothetical value and its difference from the actual deflection caused by the combined effects of electrode and body potentials.

The resistance of the body may be calculated from the experiments in which the Gordon cell was employed. With this method the sensitivity of the galvanometer was reduced to .01 of its full value. Under these conditions the deflections usually began at about 400 mm. and rose to 600 mm. in a few minutes, seldom going much beyond that value. The e.m.f. of the cell used is .67 volts. From this it is calculated that a deflection of 500 mm. indicates a body resistance of slightly over 6,000 ohms, a deflection of 600 mm. slightly over 5,000 ohms. From this, in turn, it can be estimated that under average conditions of body resistance, a deflection of 500 mm. with the galvanometer at its full sensitivity connected with the hands and without the Gordon cell, indicates a body potential of about .006 volt. This is about the largest deflection we have observed in the present experiments. The variations in body resistance under varying conditions are such that these values are only rough approximations. In some cases the resistance was found to be as great as 35,000 ohms.

Thus it is clear that a difference of potential exists between the fingers which produces a considerable deflection in a sensitive galvanometer. But it does not follow from this that changes in the initial deflection following emotional stimuli are caused by changes in potential, for, with a constant potential difference, marked changes in resistance would produce changes in deflection. However, examination of deflections produced in the word tests shows that resistance changes can not alone account for the phenomena, as

the deflections sometimes increase and sometimes decrease in response to stimuli, and, furthermore, they often cross the zero point, indicating an actual reversal of the current; and in general the size of the reaction deflection seemed to be independent of the amount of the initial deflection. Clearly then, the deflections following stimuli are due in part, if not wholly, to changes in the electro-motive difference of potential between the immersed fingers.

To study the influence of resistance changes, the second method was used, namely, the introduction into the circuit of the Gordon cell in series with the body and the galvanometer. Owing to the magnitude of the current, the sensitivity of the galvanometer was reduced one hundred-fold by means of the shunt. As stated above, the deflections thus caused ranged generally between 500 and 600 mm. If a series of word stimuli was then tried, the deflections which resulted invariably consisted in an increase in the initial deflection. Their average magnitude was between 10 and 20 mm. and they rarely exceeded 60 mm.; thus the maximum deflections indicated an increase of about 10 per cent. in the current passing through the body. At first sight it might appear that here also the deflections are due to electrical potential in the hands augmenting the current of the cell, but the fact that the deflections here are all in one direction, while with isopotential electrodes they may be in either, is much against it. Furthermore, a little quantitative study shows that a difference of potential of the magnitude detected with isopotential electrodes could not possibly produce such large deflections as are seen with the cell current. The galvanometer being at .01 of its full sensitivity which is employed with isopotential electrodes, it would require 100 times as much e.m.f. to produce a given deflection as it does to produce the same deflection at full sensitivity, and yet the deflections in the two cases are found to be of about the same magnitude. With isopotential electrodes and the galvanometer at full sensitivity, the deflections following stimuli rarely exceed 100 mm. It would require 30 times the e.m.f. which this indicates to produce a change of 30 mm. with the sensitivity reduced, and yet 30 mm. is by no means an infrequent deflection with the Gordon cell. It follows from this that electro-motive changes can not account for the deflections observed when a strong outside current is used. In short, *emotional reactions are accompanied both by changes in the difference of potential between the immersed fingers and by changes in the resistance of the body.*

The physiological basis of the electro-motive phenomena should be considered under the headings already enumerated. "Action currents" in voluntary muscles are a very improbable cause, for

contractions of the voluntary muscles are not felt by the subject to occur during the experiment and if they existed they would not be likely to escape detection. In a special experiment, the effect of contracting voluntary muscles was studied as follows: The subject, lying motionless with the hands strapped in place and the fingers in the isopotential electrodes, vigorously exerted antagonistic muscles in the arm without moving it, and gave simultaneously a verbal signal. The observer noted and recorded the deflections. Deflections regularly followed the exertions, differing from those of emotional stimuli chiefly in having a shorter latent period. They followed the exertions by an interval of a second or less, whereas in the case of emotional reactions the interval is about three seconds. In this series, six contractions were made in the right arm and seven in the left. In every case, the deflection following was in the direction which indicated a relative fall of potential in the finger of the arm in which the muscles were exerted. The experiment was repeated with two subjects, one new to the experiment, and the results were almost uniformly consistent with the foregoing. This harmonizes with the view that the deflections in this case were the result of the "action currents" of the muscles, for muscular contraction is characterized by the release of negative electrical charges. The deflections in these experiments were rarely greater than 40 mm. and yet the muscles were exerted vigorously. It is, therefore, extremely improbable that contractions of voluntary muscles so slight as to escape the subject's attention would produce "action currents" great enough to give the deflections of 50 mm., sometimes over 100 mm., which follow emotional stimuli. Voluntary muscle, therefore, may be excluded with a reasonable degree of certainty.

Smooth muscle fibers in the blood vessel walls might give off "action currents" that would produce the deflections and the curve of their contraction is much more like the curve of the deflections than is that of striped muscle. The experiment of Sidis and Kalmus with Esmarch bandages in preventing effective vaso-dilatation probably had little effect on the vaso-motor nerve impulses or on the resulting release of muscular energy; so that "action currents" may still have emanated from the vascular walls. However, other evidence led us to believe that this plays at most a minor part in producing the deflections, as will be explained later. "Action currents" in nerve trunks were not available for separate study. Like those in the vascular walls, we could neither prove nor disprove their influence, but believe that they also play at most a minor part.

The remaining tissues whose "action currents" might cause the

deflections are the glands in the skin, of which the sweat-glands are the most numerous and active. The literature concerning glandular "action currents" is not altogether satisfactory. Lillie,[4] in presenting a hypothesis to explain "action currents" on the grounds of relative permeability to ions in cell membranes, implies that cell activity in general is attended by a release of negative charges. Loeb[5] implies the same thing. It is not clear whether the generalization is based on muscles and nerve alone or whether glands have also been shown to release negative charges. Waller,[6] in "The Signs of Life," shows that in a frog's skin the "action current" is outgoing, that is, the outer surface has a higher potential than the inner. He confuses his electrical terminology and his explanation is unsatisfactory. Bayliss and Bradford[7] showed peculiar variations in the "action currents" of the skin of frogs related to the season of the year. It seems that these phenomena are too obscure to be of value as a basis of comparison with the phenomena in human skin. Mendelsohn[8] in the "Dictionnaire de Physiologie" reports similar findings in the frog's skin, but states that in the paw of the cat, when the sciatic nerve is stimulated, there is an in-going "action current" accompanying the secretion of sweat. Waller also quotes the previous observation of Tarchanoff, that under stimulation of a variety of types, "parts of the skin in which sweat-glands are most abundant become negative to parts containing few glands" (Lecture VII., p. 124). Thus experimental evidence concerning mammalian skin containing sweat-glands shows that in action the surface potential is relatively lowered. This agrees with Lillie's implied generalization concerning the release of negative charges in active tissues, and it is probable that human sweat-glands would show similar "action currents."

If the negative charges released from the sweat-glands produce electro-motive phenomena, we should expect the difference of potential between the hands to be slight, since the sweat-glands of the two are, as far as we know, alike and should produce approximately equal electrical charges. The difference of potential should occur only when the glandular activity in one hand is for some reason greater than that in the other, and should in most cases cause de-

[4] R. S. Lillie, "The General Biological Significance of Changes in the Permeability of the Surface Layer or Plasma-membrane of Living Cells," *Biological Bulletin*, Vol. XVII., pp. 188–208.

[5] J. Loeb, "Dynamics of Living Matter," pp. 68–69.

[6] Richet's Dictionnaire de Physiologie, Mendelsohn's article on "Electricité," Vol. V., p. 350.

[7] Bayliss & Bradford, *Journal of Physiology*, Vol. VII., p. 217.

[8] Waller, "The Signs of Life," Lecture IV.

flections in one direction as often as in the other. This is precisely what occurs in a series of reactions; the stimulus may be followed by a positive or negative deflection. Neither seems to predominate; the galvanometer may cross the zero point several times during an experiment. It is, however, characteristic of the deflections that they tend to be in the same direction as their immediate predecessors, that is, there is apt to be a fairly long series of consecutive positive deflections, and when after some irregularity a negative deflection appears, it is apt to be followed by a series of negative deflections. While this picture agrees with what we should expect if sweat-gland activity were the cause, we should expect it just as much if the "action currents" came from the muscles of blood vessels. Some distinguishing test should be found. Two methods of differentiating were tried; one was to compare the electrical potential of portions of the integument known to differ in the abundance of sweat-glands; the other was to ascertain the influence of drugs on the phenomena.

First we attempted to eliminate the sweat-glands from the electrodes altogether by the method described by Sidis and Kalmus, coating the immersed skin with shellac and paraffin, leaving only the finger nails uncovered, and comparing the result with that obtained with the bare skin. The middle fingers were covered with two coats of shellac and one of paraffin. As a control experiment, the fingers thus coated were inserted into the electrodes before the paraffin was scraped from the finger nails. A deflection of + 5 mm. resulted, and on reversing the fingers with respect to the electrodes the deflection was reversed to — 6 mm. This showed that even this insulation was not complete, since the difference of potential between the fingers caused a measurable deflection. With the fingers in position, the effect of a strong stimulus was tried. An operatic graphophone record was used which had previously given rise to large deflections under the usual experimental conditions. At the climax of the piece, where the subject was aware of the most intense affect, a deflection of 2 mm. was noted. This observation suggests that the conclusion of Sidis and Kalmus that "the skin has little or nothing to do with the phenomena" (because when the skin is covered with shellac and paraffin, leaving only the finger nails exposed, deflections are still obtained), is not necessarily correct. Even if the insulation had been perfect, their experiment would have proved only that something else besides sweat-glands could produce deflections; it could not prove that sweat-glands play no part. After the control experiment, we scraped the finger nails bare, leaving the skin coated and repeated the record, then repeated it a third time

with the fourth fingers (not coated) in the electrodes. The deflections in each case amounted to only 1 mm., which indicated either that the skin resistance was too high or the electrical reactions too sluggish at that time to furnish any satisfactory data. This experiment seemed to us important and would have been well worth repeating had time permitted. It was immediately followed by a similar experiment with the Gordon cell current, which threw considerable light on the resistance phenomena and will be described under that heading.

At other times significant results were obtained by immersing skin surfaces with different degrees of abundance in sweat-glands. If active sweat-glands produce negative charges which cause deflections, increase of activity must cause a fall of potential in the skin, and the more active the glands, the greater will be the fall of potential. If, however, in two skin surfaces unequally supplied with sweat-glands, the difference lay only in the number of glands, the individual glands all being equally active, the two surfaces would be electrically equivalent, for the glands are arranged, so to speak, in multiple arc, and if all developed the same potential, the resultant potential of the whole surface would be no greater than that of a single gland. A surface more richly supplied with glands than another can only undergo a greater fall of potential if the glands are individually more active as well as more numerous. It is well known that the palms of the hands are richer in sweat-glands than the dorsal surfaces, whereas there is little difference in vascularity between them. This fact might enable us to secure evidence to differentiate between vascular and sweat-gland activity. The relative potentials of these surfaces were tested by the use of soaked cotton pressed into the electrodes (not in funnels). With the dorsal surfaces of the two hands in contact with the fluid of the two electrodes, the reading was — 5 mm.; with both palms in contact + 6 mm.; with the right palm and left back — 36 mm.; with the right back and left palm + 21 mm. In all these, the right hand electrode was connected with the positive pole of the galvanometer. The experiment was repeated with similar results. This indicates that in each case the palmar surface has a lower potential than the dorsal surface of the other hand and the difference of potential is greater than that which exists between homologous surfaces. This evidence accords well with the above-mentioned observations of Tarchanoff cited by Waller, in which similar differences of potential were seen to be developed under the influence of various stimuli. It distinctly favors the view that sweat-glands reduce the potential of the skin, but it does not demonstrate that the deflections which

accompany emotional reactions are due to glandular activity. To test this, a certain graphophone record, which at a certain specific point always produced an appreciable emotional reaction in the subject, was repeated three times; first, while the backs of the hands were in contact with the solutions, then with both palms, and finally, with the right palm and left back. If the emotional reaction in the three cases were the same, we should expect a progressive increase of deflections, for in the more active palms there would probably be developed a greater difference of potential than in the less active dorsal surfaces, and in the third case, the difference in the fall of potential between the active palm and the less active dorsal surface should be the greatest of the three. In this case the subject reported as might be expected, that the emotional reactions were not the same, but progressively less each time. The three deflections in their order were 3 mm., 7 mm., and 3 mm. Another record was employed, first with both palms in contact, then with the right palm and left dorsal surface. Two strong affects were felt the first time, producing deflections of 5 mm. and 7 mm. The second time the corresponding points in the music caused much weaker affects, which gave deflections of 7 mm. and 4 mm. In the last of each series, where one palm and one dorsal surface were employed, the affects were marked by augmentation of the existing deflections, which fact harmonizes with the assumption that the deflections are caused by increase of sweat-gland activity. Time prevented further repetitions which should have been made with long series of association words. These experiments, though wholly inadequate for conclusions, suggest that during emotional reactions there is probably a greater fall of potential in the palm than in the dorsal surface. They should be repeated many times before substantial inferences could be drawn. The best test would be to use two galvanometers measuring simultaneously the same reactions by the two methods.

It may be well here to mention a peculiar phenomenon noted in studying the possibility of error arising from varying the depth of the immersion of the fingers. It was found that when the subject moved his fingers in and out of the tubes, varying the depth of immersion from about 3 cm. to about 6 cm., a change in the deflection occurred as follows: an increase in the depth of immersion of one finger produced a change in the same direction as a decrease in the depth of the other. This was verified by two long series of experiments on two subjects and in both the changes followed this principle in almost every case. The few exceptions, 11 out of a total of 127, may easily have resulted from affects which are not subject to control; they do not disprove the regularity of the tendency. This

phenomenon can not be explained by the fact that greater immersion decreases the resistance. If that were the case, increase in the immersion of either finger would increase the deflection. The explanation suggested by Professor T. W. Richards is that near the base of the finger, the skin has a lower potential than near the top, and this appears to be the only reasonable explanation. If the electrical potential is caused by sweat-glands, it would indicate that the glands near the base of the finger are the most active.

Another experiment should be mentioned here as bearing on this phase of the question. A series of word tests was given when the subject had two fingers of the same hand in the two electrodes. These fingers were then removed and corresponding fingers of opposite hands were introduced and another series of word tests given. Again two fingers of the same hand were introduced and a third series given. The reaction deflections were of about the same magnitude in all three series, varying from 1 mm. to 20 mm. In the first series, the initial deflections were much larger than in the other two, and the reaction deflections, although of about the same magnitude, differed from those in the other two series in that they were all positive, thus being augmentations of the initial deflection which was positive, whereas in the two latter series, some were positive and some negative. This would indicate that in the first series one finger was inserted relatively deeper than the other, so that skin of lower potential was immersed. The uniformly positive reaction deflections here are significant, as tending to show that they were caused by a fall of potential in the more active skin surface and were probably produced by activity of those glands giving rise to the initial deflection. In the other two series, where the initial deflection was lower, the fingers were probably immersed to more nearly equivalent depths and the reaction deflections were sometimes positive and sometimes negative, as the activity of one or the other finger predominated. The fact that the deflections in all three series were of approximately the same magnitude is also in favor of the view that the essential activity is in the skin or superficial layers rather than in the muscles or large nerve trunks, for these would be apt to influence opposite hands far more differently than fingers of the same hand.

Further evidence on the relative influence of glandular and vascular activity was sought by the use of pilocarpine and atropine. Of these atropine should furnish the better evidence as it paralyzes the nerve endings in the sweat-glands, suppressing the secretion, while it somewhat increases vaso-dilatation, and if the essential activity is vascular, it undoubtedly consists in dilatation, not con-

striction, for experiments with the current from the Gordon cell show that affects are accompanied by decrease in body resistance, which could hardly result from vaso-constriction. If the deflections are chiefly caused by vascular action, the effect of atropine upon them would be difficult to predict without more detailed knowledge of its action than we possess. If it increased the susceptibility of the vessels to vaso-dilator stimuli, it should increase the deflections. If it caused them to dilate nearly to their full capacity, it should diminish deflections by limiting further dilatation. In any case, the action of atropine on the vascular system is slight and it should not diminish deflections due to vascular activity to any marked extent, whereas its paralyzing action on the sweat-glands is such that it should greatly diminish deflections caused by their activity. Pilocarpine stimulates the nerve endings in the sweat-glands, increasing the secretion; it also causes some degree of vasodilatation, which Cushny considers merely incidental to the increased activity of cutaneous glands. The prediction of its influence on vascular response to stimuli is as indefinite as it is with atropine and it is uncertain how we should expect it to influence the deflections resulting from vascular activity. Moreover, equal uncertainty attaches to the prediction of its influence on deflections assumed to result from sweat-glands; it hinges on the question whether the stimulation of the drug is of a nature which renders the glands more susceptible to other stimuli or less so. If pilocarpine merely increases the secretion of sweat without rendering the glands more responsive to other stimuli, there would be merely an approximately symmetrical fall of potential in both fingers which probably would not influence the deflections. In short, if the sweat-glands are the chief cause of deflections, atropine should greatly diminish them, while the effect of pilocarpine is not predictable. If vascular changes are mainly responsible, neither atropine nor pilocarpine should produce a very marked effect, and what effect they did produce might be either increase or decrease. The method of testing the effects of these drugs was as follows: The subject reclined as usual with the middle fingers in the electrodes and responded to a series of test words, the deflections being recorded by the observer. The drug was then administered subcutaneously without disturbing the position of the subject. After the action of the drug had begun to manifest itself, a second series of words was given. The body resistance was measured before and after the experiment by means of the Gordon cell. The experiment with pilocarpine was made with two subjects. In one subject it appeared to increase the difference in potential between the hands, in the other to decrease it; in both subjects the

average magnitude of the reaction deflections was decreased. Further details are omitted as the uncertainty regarding the exact action of this drug renders the results of little significance in the question at hand. The only evidence of value in the drug experiments is that furnished by atropine.

The effect of atropine was studied by the same method as that employed with pilocarpine. In the first subject a hundredth of a grain was given after the first series of words, and after a pause of twenty minutes a second series of words was given. Then as the drug had produced no symptoms, a fiftieth of a grain was administered, and after fifteen minutes, dryness of the mouth being appreciable, a third series of words was tried. The results were as follows. The initial or resting deflection was less after the first dose of atropine than before, but after the second dose, it increased. The ratios of the body potential to the electrode potential as estimated by reversing the fingers were 40 to 26, 40 to 55, and 85 to 35, at the times of the three series respectively. But this method of inference can not be altogether relied upon, especially in this series of experiments in which electrodes were used of a design which was found to show changes in potential when subjected to disturbances such as might occur in reversing the hands. This point will be discussed more fully later. The average of the reaction deflections in the first series of 19 was 1.5 mm. In the second series of 20, after the first dose, it was .8 mm. In the third series of 24, after the second dose, it was .67 mm. In this same subject, the average deflection was reduced from 1.7 to 1.5 by pilocarpine. In the second subject, the same method was employed, but since some dryness was detected after the first dose of .01 of a grain, the second dose consisted of only .01 instead of .02. In this subject, the initial deflection decreased after the first dose, remaining fairly constant throughout the second and third series. Reversing the fingers gave such irregular results as to be worthless from the point of view of estimating body potential. This was probably the result of joggling the electrodes in shifting. The average of 24 reaction deflections in the first word series was 2.4 mm.; in the second, after one dose of atropine, the average of 21 was 1 mm.; after the second dose, the reflex was practically obliterated; only 4 out of 12 stimuli being followed by any deflections, and none exceeding 1 mm. In this subject, then, as well as in the other, the reaction deflections were reduced more by atropine than by pilocarpine. The results suggest that atropine probably reduced the difference of potential between the hands, but this is uncertain. It clearly reduced to a marked extent the deflections following stimuli.

On the whole, the findings concerning the influence of these drugs on initial or resting difference of potential between the hands are of little value. Moreover, the diminution by pilocarpine of the deflections following stimuli is of doubtful value since its interpretation for the reasons set forth above is not clear. The one significant result is the marked diminution of the reaction deflections by atropine. Since this drug has a marked paralyzing effect on the sweat-glands, but has comparatively little effect on the vaso-motor system, the evidence has some weight in the question at issue, and tends strongly to support the view that the sweat-glands are the chief source of these deflections.

The evidence has been given bearing on "action currents" of the various tissues whose activity might be involved. There remain for consideration electro-chemical activity between the sweat and the electrolyte, and thermo-electrical phenomena at surfaces of contact between electrically different substances within the tissues or at their points of contact with the electrolyte. The principal electrolyte in sweat is sodium chloride. Electro-chemical action between this and potassium chloride which surrounds the fingers in these experiments is so slight that it is highly improbable that it constitutes an important factor in the deflections under consideration. The same is true of thermo-electrical phenomena, for the substances within the tissues are such that even with large temperature changes at their points of contact, the e.m.f. developed in this way would be very slight and it is probable that the temperature change in active tissues is extremely small. That thermo-electrical phenomena at the point of contact between the tissues and the electrolyte are not of much consequence is indicated by the fact that deflections produced when the electrodes were maintained at body temperature by a thermostat were not found to differ in any way from those produced when the electrodes were at room temperature, several degrees cooler than the body.

The foregoing statement of evidence and inferences concerning the causation of electro-motive changes in the hands practically eliminates all factors except "action currents" in the muscles of the vascular system and in sweat-glands from playing any considerable part. The various facts noted all tend to support the view that sweat-gland activity is the most important factor, although none can be said definitely to prove it. None of the facts seem to oppose this view in any way. Obliteration of the deflections by atropine supports the sweat-gland hypothesis fairly strongly and tends to indicate that if vaso-motor activity plays any part, it is at most a small one.

The resistance changes must depend chiefly on vaso-dilatation or on sweat-gland activity. This assumption is due not only to the absence of any other probable cause, but is supported by the following experiment. The resistance of the body was measured by the use of the Gordon cell, with the middle fingers of the two hands immersed in the electrodes, and was found to be about 18,000 ohms. The fingers were then soaked in warm water and again inserted in the electrodes. The resistance was then found to be about 14,000 ohms. Next the two index fingers, which had not been previously soaked, were inserted and the resistance was found to be 35,000 ohms. Then the index finger and the fourth finger of the same hand were introduced into the electrodes and the resistance was found to be 31,000 ohms. It was then noted that when the index finger and the middle finger of the same hand were introduced into the electrodes, the middle finger only having been previously soaked, the resistance was higher than when the middle fingers of the opposite hands, both of which had been previously soaked, were employed. This shows that by far the greater part of the body resistance is in the skin or superficial layers. The resistance of the structures within the skin forms so small a part of the total resistance that it would have to be enormously reduced during an emotional reaction to produce the changes often noted amounting to 10 per cent. of the total resistance. It is impossible that there should be sufficient change in internal resistance to produce the observed deflections. Therefore, the cause of the resistance changes noted must lie chiefly in the surface layers.

We have then to consider the relative importance of vaso-dilatation and sweat-gland activity in the causation of the observed resistance changes. It has been noted that the deflections following emotional stimuli with the cell current always marked a lowering of body resistance. Immediately after the experiment already described (p. 10), in which the skin was coated with shellac and paraffin in the study of potential changes in the hands, the Gordon cell was introduced and a similar experiment was performed to throw light on the corresponding resistance changes. The galvanometer was shunted as usual to .01 of its full sensitivity. The fourth fingers (not coated) were inserted in the electrodes and a deflection of 195 mm. was observed. The middle fingers, coated as already described with shellac and paraffin, except on the surface of the nails, were then inserted. A deflection of 58 mm. resulted. A graphophone record was then played which at a definite point produced a fairly marked emotional reaction in the subject. At the time the affect was felt, the galvanometer reading rose from 64 mm., where it had gone at the beginning of the record, to 65 mm. The index fingers

(not coated) were then inserted, and a deflection of 100 mm. resulted, rising during the first part of the music to 170 mm. and at the point where the marked affect was felt, to 210 mm. The nails of the middle fingers were then coated with paraffin, and the fingers inserted as before. The deflection resulting was 33 mm. The same record was then played, and at the point where the marked affect was felt, the galvanometer reading which had remained at 33 mm., rose to 35 mm. Another graphophone record was then played in which a still more definite emotional reaction occurred at a certain point. The galvanometer reading during the early part of the music was 26 mm. When the affect occurred, it rose to 29 mm. This was repeated without removal of the fingers. The affect was marked by a rise from 25 mm. to 28 mm. The paraffin was then scraped from the finger nails, leaving the remainder of the skin still coated and the deflection following their insertion was 136 mm. The record was repeated and when the affect occurred, the reading rose from 140 mm. to 144 mm. The index fingers (not coated) were then inserted and the galvanometer read 200 mm. The record was repeated and when the affect occurred, the deflection rose from 210 mm. to 265 mm. In these experiments, the deflections are inversely proportional to the body resistance; thus a deflection of 100 mm. indicated a body resistance of 35,000 ohms; a deflection of 25 mm., a resistance of 140,000 ohms. It is clear that very considerable conduction occurs through the finger nails, since covering them with paraffin reduced the deflection from 60 mm. to 30 mm., and scraping them bare again raised it from 26 mm. to 136 mm. The highly vascular tissues beneath the finger nails being brought into fairly close relation with the electrolyte, we should expect that if vaso-dilatation were the chief factor in the reactions, the deflections marking an affect would be about the same percentage of the total deflection as when the skin is exposed. In the first experiments with the finger nails bare and the remainder of the fingers coated, we note an increase of the initial deflection of 1 mm., or about 2 per cent. With the bare fingers, the conduction was only increased three fold, but the same passage in the music caused a deflection of 40 mm., over 20 per cent. of the total, and yet the affect was probably less in the second case than in the first. With the second graphophone record, it was shown that even when the fingers were completely coated, a deflection of 3 mm. occurred in each of two successive tests; with the finger nails scraped bare, although the total deflection was increased from 25 mm. to 130 mm. due to conduction through the finger nails, the deflection marking the affect was only 4 mm. With the bare fingers, although the total conduction was increased only in a ratio of

200 to 130, the affect (by this time distinctly weakened by repetitions of the stimulus) caused a deflection of 55 mm. Thus it is seen that increasing the conduction through a vascular region without sweat-glands did not cause an increase in the reaction deflections, whereas the exposure of skin containing sweat-glands to the electrolyte greatly increased these deflections. It is not even necessary to assume that vaso-dilatation caused the small deflections observed when the finger nails were bare, since approximately equal deflections were observed when they were covered, and may well have been caused by the sweat-glands in the skin, since the insulation has been shown to be incomplete. Thus, this experiment furnishes strong evidence tending to prove that the resistance changes are chiefly, if not wholly, due to sweat-gland activity.

The evidence furnished by drugs concerning the resistance changes was slight. In neither subject were word tests employed with the cell current in the pilocarpine experiments. In each, however, the resistance was measured before and after the administration of the drug. In one, there was a slight increase; in the other, a considerable decrease. With atropine, in only one subject was the resistance measured before and after, and in this case, it remained practically the same. In the other subject, the resistance was not measured before the administration of the drug; but at the end of the experiment, after the obliteration of the deflections caused by body currents had been shown, the cell was introduced, and the deflections following the test words were almost as completely obliterated. If the reduction of resistance is due to sweat-gland activity, we should expect a similar reduction to follow the administration of pilocarpine. That this was not so in one of the subjects, would seem at first sight to militate against the sweat-gland hypothesis. However, it is perfectly possible that the way in which the sweat-glands lower resistance is by the temporary distention of sweat tubules with secretion following a fairly sudden access of activity. It is quite conceivable that the production of sweat under the influence of pilocarpine is so gradual that the tubules carry off the sweat as fast as it is produced, and that the distention is, therefore, not appreciable. The failure of atropine to increase the resistance may likewise be due to the fact that the tubules are normally empty and the paralysis of the sweat-glands can not, therefore, make them any emptier. The fact that the sudden fall of resistance following stimuli was obliterated by atropine is strong evidence that it is caused by sweat-gland activity. Furthermore, a study of the structure of the skin suggests that on physical grounds it is probable that a marked fall of resistance could be more easily accounted

for by the filling of tubules with sweat and the resulting establishment of many columns of conducting fluid than by the greater abundance of blood beneath the skin, which results from vaso-dilatation. It seems highly probably, then, that the resistance changes are caused chiefly, if not wholly, by the activity of the sweat-glands.

It has been demonstrated that emotional states are marked by electro-motive changes in the skin and by lowering of body resistance. It has been shown that the electro-motive changes probably result chiefly from sweat-gland activity and that there is somewhat greater probability that the same activity is the cause of the resistance change. The probability in both cases is reinforced by the harmony of these findings. It is further significant that the deflections produced in the two ways are similar in character. In each case, the deflection usually begins after a latent period of about 3 seconds, and rises rapidly to a maximum from which it soon starts to fall gradually toward the starting-point. There is this difference; the resistance deflections are much more regular and almost always adhere closely to this type; the deflections caused by electro-motive changes are irregular, the latent period may be prolonged and the main deflection may be preceded by a short preliminary deflection in the opposite direction; and instead of returning regularly almost to the starting-point after the maximum is reached, it may remain there, or after a pause go even higher. These facts are in harmony with the supposed difference in the causation of the two types of deflection. The tubules, suddenly distended with fluid, would be expected to empty themselves gradually and at a uniform rate, as their elastic walls contracted, and the original resistance would then be reëstablished. The difference of potential set up between the fingers by variable differences in the activity of the two skin surfaces could not be expected to subside with the same regularity.

It can not be said that anything final is established by these few experiments, where so many intricate and inseparable factors are involved; but it seems eminently probable in view of the harmony of the evidence that the psycho-physical galvanic reflex is principally the result of a single physiological activity, the secretion of sweat, which manifests itself physically in two ways, by changing the electrical potential of the surfaces of the body and by lowering the resistance of the skin.

II. SOURCES OF ERROR IN PRACTICAL APPLICATIONS

Experiments were conducted to study the various sources of error which should be met in applying the deflections to the analysis of emotional reactions. An effort was made to determine the magnitude of error which might be expected from unconscious motions of the fingers which would change the depth of immersion. The subject stood before the tubes and moved his fingers in and out of the solution, varying the depth of immersion from about 3 cm. to about 6 cm. The character of the changes resulting has been described and discussed in connection with the electrical potential of the skin. What concerns us now is the magnitude of the deflections. The maximum deflection produced by this change in the depth of immersion of one finger, after the initial changes due to soaking had ceased, was 40 mm. with one subject, and 28 mm. with the other. From this, it may be inferred that motions of the fingers which were too small to be perceived by the subject would not cause any considerable error, and even motions as great as the apparatus would allow would not produce deflections large enough to simulate or obscure the reaction deflection of a moderate affect, owing also to the differences in latent period.[1]

An attempt was made to ascertain whether a convenient means of insulation could be found which could be applied to the skin at the level of immersion, so that the surface in actual contact with the fluid should be absolutely constant. Shellac was found to be wholly inadequate, as even when the fingers to be immersed were completely covered with two coats, the first drying before the second was applied, and the second drying before testing, deflections resulted almost as great as those obtained without insulation. It has already been stated that even when a coat of paraffin was added to shellac, insulation was not complete. When the fingers completely covered by rubber cots were placed in the electrodes, no deflection was produced. The insulation was here complete. Rubber cots were then applied with their tips cut off so that a constant surface was exposed beneath the fluid. Changes in the depth of immersion here caused changes in the deflections similar to those thus caused without insulation, but much smaller. The explanation of this is difficult. If any fluid worked up under the edge of the rubber, it must have been an exceedingly thin film and its resistance very

[1] Cf. Peterson and Jung, *Brain*, XXX., p. 159.

high, yet it might conceivably account for the changes. The decrease in resistance in the fluid resulting from bringing the finger nearer to the mercury could not amount to more than 4 or 5 ohms, and this compared to the 5,000 or 6,000 ohms in the body is too small to account for the changes. It is possible that the increase in pressure from deeper immersion causes a better saturation of the skin or in some such way improves conduction. It was concluded from these experiments that the available methods of insulation serve rather to give a false sense of constancy of contact than to give any real constancy, and it seemed, therefore, better to trust to the stationary position of the hands, which is sufficiently reliable for practical purposes.

The question of thermo-electrical phenomena brings up important considerations which were dealt with as follows. The temperature coefficient of the calomel electrode is .0006 volt. That is, if one electrode becomes heated 1° C. more than the other, the potential difference between them becomes modified to the extent of .0006 volt, which is about the average difference of potential produced by the body, and .1 of the approximate maximum in our experiments. When the fingers are inserted in the tubes whose temperature is approximately that of the surrounding air, the fluid at the surface is warmed. Under these conditions, convection is not favored, and the heating of the lower portions of the tubes containing the calomel and mercury is very slow. However, some change of temperature occurs throughout the tubes, and though this tends to be nearly the same in the two electrodes, it is probable that in a fairly long experiment one electrode will be heated somewhat more than the other, perhaps to the extent of one or two degrees centigrade. Assuming all conditions within the body to remain constant during the experiment and the body resistance to be 6,000 ohms, a change of 1° C. would cause a change of 50 mm. in the deflection of the galvanometer. These figures were verified by the following experiment. The temperature of one electrode was raised to 35° C., the other being maintained at 20° C. The galvanometric deflection, which varied between 20 and 40 mm., when the electrodes were at the same temperature, was raised to over 700 mm. by this change. This indicates a rise in the deflections of 47 mm. per degree, which is in close agreement with the calculated value. If any such change resulted from warming of the electrodes by the fingers, it would occur gradually during the course of the experiment, and hence would not impair the value of a given electric bodily reaction whose duration is only a few seconds; but it would change the starting-point of the individual deflections and possibly falsify the relation between those at

the beginning and those at the end of the series. It, moreover, confuses the problem of the causation of the deflections by the addition of a new factor. To measure the actual effect of heat from the fingers upon the deflection, two of the electrodes (Nos. I. and V.) were connected with the galvanometer and the circuit closed with the electrolyte in the Y-tube. The subject then inserted his fingers into the tubes, completely insulated from the fluid by thin rubber cots, the Y-tube being still in place to complete the circuit. Subsequent changes in the deflection were thus due solely to heat acting in two ways, through the change in electrode potential and through lowering the resistance of the electrolyte. In ten minutes the deflection rose to 105 mm. The finger was then withdrawn from one of the tubes (No. V.); in five minutes more the reading was 110. The remaining finger was then transferred from tube I. to tube V., and after eight minutes, the reading was 125. The further changes were as follows: finger transferred to I., after six minutes, 148 mm.; transferred to V., after ten minutes, 144; transferred to I., after five minutes, 160. At this point, the fingers were removed and the bottom of tube V. was grasped with the hand. This caused a comparatively rapid rise to 190 mm. Tube I. was then grasped with a resulting fall in the deflection. This experiment shows that the effect of warming with the inserted finger was to materially lower the resistance of the electrolyte, while owing to the lack of convection, no appreciable change in potential occurred. The potential change which depends upon the temperature of the mercury, appeared only when the bottom of the tube was grasped. When the Y-tube is replaced in the circuit by the human body, the change in the resistance of the electrolyte becomes negligible. It seems, therefore, that for most practical purposes, experiments conducted at room temperature are satisfactory. But for the sake of eliminating as far as possible the thermal factor in studying the cause and extent of the phenomena, it seemed worth while to introduce a thermostat to keep the electrodes as nearly as possible at body temperature. Another advantage of this procedure is that it prevents the increase of skin resistance, which is apt to occur if the circulation is sluggish when the skin is in contact with cool fluid.

A thermostat was, therefore, arranged consisting of a long iron tank full of water placed transversely on the floor under the massage table, heated by an electric coil and regulated by an acetone reservoir with platinum and mercury contact and a rheostat. An electric stirrer was introduced and it was found that with this apparatus the variation in temperature did not exceed one or two tenths of a degree centigrade. It was necessary with the thermostat to employ

electrode tubes of a new design, for, if the original tubes were immersed in the water bath, the platinum wires sealed into them at the bottom point could not be effectively insulated from the water and a short circuit would result. For this reason, tubes were made having a diameter of 5 cm. for most of their length, but narrowing at the bottom to a diameter of 2 cm. A short platinum wire was welded to the end of a copper wire and passed through a slender glass tube until only the platinum protruded from the end. This end of the glass tube was sealed off, and bent upwards at a sharp angle. This glass tube was placed in the larger electrode tube with the protruding platinum point at the bottom and mercury was added till the platinum was wholly covered; next above this was a layer of calomel and the tube was filled with potassium chloride. As with the other tubes, both the calomel and potassium chloride had been prepared in the usual way for non-polarizable electrodes. In this way, the current was led off above the level of the water bath, and a short circuit was avoided. In the course of the experiments with these electrodes, a new and serious source of error appeared, to which allusion has already been made. Although the inner tubes containing the conducting wires were tied in such a way as to hold them as securely as possible in one position, it was found impossible to wholly immobilize them. It might be possible to seal them so as to do so. When any joggling occurred, moving the platinum contacts within the mercury, changes in electrode potential resulted, showing themselves by considerable deflections of the galvanometer. As long as care was taken to avoid joggling, these changes did not occur. These tubes were used in most of the later experiments and it is believed that error was not permitted to occur in this way except in the instance already mentioned. However, the danger of error arising in this way during the conduct of experiments is considerable, especially if coöperation is at all questionable. Since the potential changes arising from warming the electrodes are of no practical consequence, it seems advisable in the great majority of experiments to dispense with the thermostat and use electrode tubes such as were first described with platinum wires sealed into the bottom points, thus eliminating the more serious source of error.

In relation to such reactions as the emotional, it is reasonable to expect greater uniformity in the use of a cell current, if our conclusions regarding the physiology of the phenomena are correct, for, as has been pointed out, deflections with isopotential electrodes depend upon the skin surfaces of the two fingers being differently affected. It is obvious that an intense affect stimulating the sweat-glands of two fingers to great activity might stimulate them almost

equally; whereas, a slight affect only weakly stimulating the sweat-glands might happen to stimulate those on one side much more than those on the other. Thus the intense affect would cause a smaller deflection than the slight affect. In a long series of tests, however, the average of the deflections following strong stimuli would tend to be greater than the average of those following weak stimuli, for with large potential changes in the skin, the difference between the two sides would in a majority of cases be greater than with small potential changes. With the cell current, we should expect more regularity, for the deflections are caused by lowering of the resistance which results from the secretion of sweat and this should occur invariably with strong affects. Just such a difference was noted between the body current and the cell current. With the former, marked affects occasionally occurred, showing only small deflections, whereas with the cell current, this was almost never the case. It would seem to follow from this that the use of the cell current is the more reliable method of measuring affects.

III. ON THE REACTION DEFLECTION AS RELATED TO THE INTENSITY OF EMOTIONAL RESPONSE WITH SPECIAL REFERENCE TO THE ASSOCIATION EXPERIMENT

The purpose of the accompanying remarks is to further describe a number of experiments that were made with a view to testing the criteria of the emotional reactions in the association experiment. No one who has followed the recent tendencies in the literature of the association test can fail to appreciate how closely these newer viewpoints are bound up with questions of affective reaction; but it is in every way desirable to study these reactions as quantitatively as may be, though the means at present to our hands are far from perfect.

Under present conditions the only scientific approach to this problem is the correlation of objective criteria of emotional reaction with those of the introspection. There is at present no criterion of mental reaction so trustworthy as the subject's own honest and careful account of it. Sources of error in the introspection of emotion there are, indeed, and experiments such as those to be described throw light on their nature, but the writers are much out of sympathy with the practise of going over the head, or more accurately, routing under the heels of introspection for a psychogenic explanation of any phenomena without the assurance that the phenomena in question are eliminated from the physical (or logical) sources of error in the method.

The basis of the mode of inquiry is, then, to present to the subject situations of greater or lesser emotional appeal, to note the character of objective reaction thereto, and to compare it with the subject's own account of the emotional reaction. The free association test is, as it happens, very much the best means of presenting such situations.

The objective criteria of emotional reaction in the association test may be considered as of three sorts: the character of the response word, the reaction time of the response, and the involuntary somatic reactions.

Probably one of the first things learned by an experimenter with the association test is the wide variation in the way in which different subjects "take" the experiment. At bottom, this is probably what produces the difference between *Sachlicher Typus* and *Kon-*

stellationstypus. There are differences in temperament under which some subjects react with much more egocentric responses than others; that is, the responses are chosen much more with reference to the subject's special experience. Where this is done, a *Konstellationstypus* is the general result. This varying egocentricity of the responses is, however, not wholly a matter of individual difference, for it changes not a little with the mood of the subject at different times. In so far as the responses give insight into the nature of these temperamental differences, they are of undeniable value, but they have the disadvantage of not being very coercive, because there is no certainty of how far the subject has observed or attempted to observe the conditions of the experiment in uttering the response. When response words of an intimately personal nature present themselves, pretty much every one can "dodge" and pretty much everyone does do so, to a greater or less extent. But as dodging takes time, those associations which involve suppression will tend to have longer reaction time than those which do not. The assertion of the correspondence of long reaction time with heightened emotional response has been very generally made, and well supported on theoretical grounds; but there is need of more systematic correlation of this factor with the introspective findings, before the degree of its reliability can be accurately estimated.

Whether in the nature of cause, effect, or identity, the emotional reaction is usually considered to be very intimately associated with the organic processes. The emotional reaction is as the introspection detects it; the organic reaction we may estimate with such degree of accuracy as our objective methods permit. Various aspects of the organic reaction may be considered, as the breathing, heart-rate, blood pressure and the like. Judging from the history of the problem, it would seem that the electrical reactions are those in which further study is the most immediately desirable.

Given the technique above described, the problem becomes essentially that of observing the closeness of relationship between the galvanometric reaction-deflection, and the introspectively given intensity of emotional response. Since, in addition, the association times can be recorded (by a stop-watch) without difficulty, an immediate comparison is afforded of the reliability as "*Komplexindikatoren*" of the reaction-deflection and the association time.

A satisfactory method of dealing with the introspective data is of course required. Since the essential thing to determine is the intensity of emotional reaction, the object of the experiment is best served by making the individual's task in recording this datum as simple and definite as possible. The ideal plan, of course, would be

to have the subject arrange the different emotional reactions in the order of their intensity, but this is obviously impossible. The original procedure, and that followed for the most part, was to assign the reaction to one of four groups: (A) strongly emotional, (B) rather emotional, (C) rather unemotional, (F) practically devoid of emotional reaction. This grade was determined by the subject as soon as possible after the response was given, and announced to the operator when called for. In some cases the response-words were dispensed with, and the subject remained silent except when asked for the grade; but this diminishes somewhat the efficiency of the procedure. It stands to reason that the grade was assigned without any knowledge of the deflection to which it attached.

A short representative series (no responses spoken) is as follows:

Stimulus-word	Emotional Grade		Reaction-Deflection in mm.
peevish	C		11
wrong	F		9
go	C +	the reaction was noted to "persist"	11, then to 14
where	B		20
ring	B —		12
now	F_2		8
telltale	F +		6
quiet	F_1		9
widow	C		7
amorous	B		20

In matters of this sort, the less the subject is hampered with technical definitions of the qualities to be graded, the more reliable his gradings are likely to be. It is much better to let the subjects find out for themselves what they judge by than to tell them in the beginning to judge by criteria that they can not be expected to construe in the same way as they are presented. With continued practise in the experiment, it was but natural that certain criteria should separate themselves out to the subjects' observation. These tended to reduce themselves more and more to a basis of somatic sensation, though the results are not very different, whatever criteria are uppermost in consciousness. If it be permissible to introspect introspection, the sources of error would, as a matter of experience, operate mainly in the direction of making the grades too low. With some subjects there may be in the first experiments a noticeable tendency to be chary about assigning the highest grades at all, owing to their frequent relation to intimate personal affairs. Where there is suppression, the grade is apt to be underrated. And if the emotion aroused is one that the subject regards as of a degraded origin, it may receive a low grade independently of the fact that the emotional reaction has been quite pronounced. Conversely, ideas that might

ordinarily be associated with elevated emotions may be graded high, though the ideas do not now arouse such a reaction, but this error seems to reach serious proportion only in subjects quite unpractised in introspection. There seems to be a real introspective awareness of these sources of error, and they can greatly distort a genuine correlation between the functions observed.

A more refined method of dealing with the introspective data was evolved not only to guard somewhat against these errors, but also to obviate the external difficulty that the reaction deflections could not be relied upon to maintain the same order of magnitude throughout a prolonged experiment. This procedure was to segregate the associations into small groups, regularly of five, which the subject would then endeavor to arrange in order of the intensity of their emotional reaction; or the subject would grade the words as previously, and in case of the same grade being assigned to two of the five words, would decide which of the two reactions had been stronger. As an illustration, the following words may be quoted, which were given incidentally, and not as part of a regular experiment.

Stimulus-word	Emotional Grade	Reaction-Deflection
mountain	C +	6
marry	A	25
trouble	B —	2
hope	B	5
bicycle	F	1

(The correspondence in order is here rather better than the average; it is in fact perfect except for the displacement of *mountain* which may, however, owe much of its deflection to having come first in the test.)

This is much the more satisfactory way of making the experiment, when the subject's introspective ability is sufficient to permit it.

The observed relationships between the objective and the introspective criteria can hardly be stated by any of the more evolved correlation methods, since the quantitative relations of the emotional grades are not sufficiently definite. In the original method of recording, one is practically limited to stating the central tendency of the deflections that are assigned to each group of emotional grades.

The greatest number of experiments is with F.L.W. as subject, and it is perhaps fair to add that the practise in introspection that comes with special psychological training was probably greatest in this subject.

Tabulated as above, the experiments with this subject resulted as follows:

Relation of Emotional Grade to Galvanometer Deflection and to Association Time

N. B. The figures express central tendencies only; no claim is here made for the reliability of the method in single observations.

The median association times are given in fifths of a second.

Experiments with Subject F. L. W.

Expt. No.	No. of Stimulus-words		Emotional Grades A	B	C	F	Remarks
I.	26	Av. Defl.	55	70	43	41	Body currents. Palms resting upon cotton in funnels in electrodes. No specific criterion of emotional intensity. The median association times of this experiment are included in those of the next, of which it is chronologically a part.
		Med. Time	See next experiment.				
		No. Cases	*1*	*5*	*12*	*8*	
II.	72	Av. Defl.	47	31	26	15	Body currents, middle fingers immersed in electrode solution.
		Med. Time	17	13	12	12	
		No. Cases	*5*	*17*	*25*	*25*	
III.	25	Av. Defl.	32	26	20	19	Body currents. Grading by "localized" somatic sensation.
		Med. Time	17	13.5	12+	12	
		No. Cases	*1*	*6*	*8*	*10*	
IV.	25	Av. Defl.	64	57	46	47	Body currents. Grading by "intellectual" estimate.
		Med. Time	12	11	11—	10	
		No. Cases	*4*	*6*	*8*	*7*	
V.	25	Av. Defl.	43	29	17	14	Body currents. Grading by "diffuse" somatic sensation.
		Med. Time	9	11	9.5	9	
		No. Cases	*3*	*7*	*9*	*6*	
VI.	25	Av. Defl.	68	35	28	27	Body resistance, shunt .01. Grading by "diffuse" somatic sensation. Future experiments are graded by this criterion.
		Med. Time	10+	10.5	9	9.5	
		No. Cases	*1*	*6*	*10*	*8*	

Expt. No.	No. of Stimulus-words		Emotional Grades A	B	C	F	Remarks
VII.	15	Av. Defl.	145	38	12	11	Body resistance, thermo-electric current. Difference in temperature of electrodes, approximately 14° C.
		Med. Time	Not recorded.				
		No. Cases	*1*	*3*	*6*	*5*	
VIII.	25	Av. Defl.		9	10	5	Body currents, index and third fingers of right hand.
		Med. Time		8	9	8	
		No. Cases		*5*	*10*	*10*	
IX.	12	Av. Defl.	10	3	2.5	2	Body currents, middle fingers of either hand in usual manner.
		Med. Time	13	12	10	10	
		No. Cases	*1*	*1*	*4*	*6*	
X.	17	Av. Defl.	26	10	13	10	Body currents, index and third fingers of right hand.
		Med. Time	14	12	13	11	
		No. Cases	*1*	*6*	*6*	*4*	
XI.	25	Av. Defl.	5	4.3	2.4	1.3	Body currents, middle fingers of either hand.
		Med. Time	12	13	10	11	
		No. Cases	*2*	*3*	*9*	*11*	
XII.	24	Av. Defl.	9	4.3	3.3	1.3	Body resistance, shunt .01. Electrodes in thermostat.
		Med. Time	9	10	11	9	
		No. Cases	*2*	*6*	*9*	*7*	
XIII.	23	Av. Defl.	13	6.5	5.3	6.2	Body currents, thermostat. Excluding the first two reactions (C's), which are anomalous.
		Med. Time	10	10	10	10	
		No. Cases	*1*	*8*	*9*	*5*	

Expt. No.	No. of Stimulus-words		Emotional Grades A	B	C	F	Remarks
XIV.	25	Av. Defl.	44	15	8	4	Body resistance, shunt .01, thermostat.
		Med. Time	12	11	10	9	
		No. Cases	*2*	*11*	*6*	*6*	
XV.	21	Av. Defl.	13	3	2	3+	Body currents, thermostat. Omitting the first four reactions, which though preserving the correlations, are anomalously large.
		Med. Time	16	9	10	10	
		No. Cases	*3*	*6*	*6*	*6*	
XVI.	25	Av. Defl.	7	6.6	3	2	Body resistance, thermostat. The largest deflection, 16, attaches to the stimulus-word *bitch*, assigned the grade of B +. Cf. p. 28.
		Med. Time	No responses given.				
		No. Cases	*2*	*5*	*6*	*12*	
XVII.	25	Av. Defl.	4	2.3	1.9	1.7	Body currents, thermostat.
		Med. Time	Not recorded.				
		No. Cases	*4*	*7*	*8*	*6*	
XVIII.	21	Av. Defl.	2	1	0.6	1	Under 1/100 gr. atropin, immediately after the above, and under the same external conditions.
		Med. Time	Not recorded.				
		No. Cases	*2*	*6*	*5*	*8*	

In the subjoined experiments A.F. was subject:

Expt. No.	No. of Stimulus-words		Emotional Grades A	B	C	F	Remarks
I.	25	Av. Defl.	5.5	2.4	1.4	1.6	Body resistance.
		Med. Time	8	12	12	11	
		No. Cases	*2*	*5*	*10*	*8*	
II.	25	Av. Defl.	13	6.7	3.5	2	Body currents, electrodes in thermostat.
		Med. Time	11	12	11	10	
		No. Cases	*2*	*9*	*12*	*2*	
III.	10	Av. Defl.		21	5.2	8	Body resistance, shunt 0.1.
		Med. Time		11	11	10	
		No. Cases		*3*	*6*	*1*	
IV.	25	Av. Defl.	9	4	4	2	Body currents, electrodes in thermostat.
		Med. Time	Not recorded.				
		No. Cases	*2*	*9*	*8*	*6*	
V.	20	Av. Defl.	4	1.7	0.7	1.5	Body resistance, shunt .01.
		Med. Time	Not recorded.				
		No. Cases	*1*	*5*	*8*	*6*	

In the following experiment, the responses were given without the grades, which the subject assigned afterwards from memory.

VI.	91	Av. Defl.	23	15	7	4
		Av. Time	11	12	13	12
		No. Cases	*4*	*12*	*40*	*35*

Taking into account the inaccuracies of introspection, as well as the sources of error remaining in the experimental method, these results seem to show that in central tendencies a fairly close relationship exists between the intensity of the objective reaction and the electrical disturbances in the tissues involved. In point of comparison with the association time, the relative superiority of the deflections is evident.

What the figures do not indicate, is the reliability of the method for individual cases. This is the most important practical feature of the problem, it being of some forensic interest to know with just what certainty the specially affective moments in an individual's mental economy may be objectively determined and measured. For the above form of presentation this is sufficiently well indicated in the mean variation of the association times and reaction deflections attaching to the different emotional grades. The following experiments, made some time previous to the present ones, especially well illustrate this relation, because both in the naïveté of the grading and in the intensity of the emotional reactions involved, they approximate more nearly than the present tests to the actual conditions of *Tatbestandsdiagnostik*.

Number of Stimulus-words		Emotional Grade A	B	C	F	Remarks
99	Av. Defl.	50	21	16	15	Body currents. Palms strapped to cotton in electrode funnels. Quoted from Wells and Cady, *American Journal of Insanity*, LXV., 165–166.
	M. V.	10	9	6	7	
	No. Cases	*2*	*23*	*36*	*38*	
100	Av. Time	16.5	14.0	11.8	10.9	Observe that the average and median are practically the same; the median, indeed, tending to be slightly longer.
	M. V.	1.5	1.9	2.0	1.8	
	Med. Time	16.5	15.0	12.0	10.9	
	No. Cases	*2*	*20*	*37*	*41*	

It is easily seen that the individual reactions, outside those of the A grades, are subject to so large a probable error that neither time nor deflection has much significance for placing them. The deflections which attach to the A grades are separated from the remainder by a greater margin of probability than the times are, indeed the margin is here quite considerable, and it is precisely these stronger reactions that it is psychodiagnostically most important to detect. Substantially this relation exists also in the more recent experiments.

Before finally condemning the method for the individual cases, except in the strongest emotional reactions, an examination may be made of its behavior in those cases where the associations are segregated in groups of five, and ordered in relative position. This gives a limited opportunity for correlation by the Woodworth per cent. of displacement. Thus the example quoted on p. 29 would show two displacements out of a possible 10, 20 per cent.

Arrangements of this nature were available in about a third of the experiments above quoted, totalling 36 groups of five reactions, 23 for F.L.W. and 13 for A.F. The correlation by the Woodworth per cent. of displacements is as follows for the different factors under consideration:

SUMMARY OF CORRELATIONS

The lower the figure, the closer the correlation; 50 per cent. = 0 correlation

	F.L.W.	A.F.
Defl. Emot.	27 per cent.	30 per cent.
Time Emot.	39 per cent.	44 per cent.
Defl. Time	38 per cent.	42 per cent.

The validity of these averages is limited somewhat by the fact that the differences in emotional reaction are greater in some groups of five than in others. Thus some will contain only B and C grades, while others may cover the complete range, A, B, C, F. Chance errors are much more likely to break down a real correlation in the

former case than in the latter. As a matter of fact the correlations with the deflections are more positive, the greater the range becomes.

Of special interest is the condition with the A-grades. In the arrays considered this grade is assigned fourteen times, and in thirteen cases it attaches to the greatest deflection in the array; in the fourteenth it is tied with a B+. The deflections here put in a class by themselves the reactions attaining this grade, which, for that matter, the introspection does also. Only two of these fourteen A's have the longest association time in the array; a third is tied with a C. Twice the time is actually shortest, and twice tied for shortest. The greater reliability of the deflection is here also evident.

Unfortunately it is not so evident that considerably increased deflections necessarily attach to an A emotional grade. There are uncontrolled factors which may occasion a considerable deflection in one of the lower grades. Only when the greatest deflection in the array is half again as much as the next greatest, is it possible to say with comparative assurance that one is dealing here with an emotional grade of A or B. Among the sixteen cases in which such a difference exists there are two exceptions, both in F.L.W.

Special attention should be called to the fact that the correlation of the two objective criteria—the deflection and the time—is but slightly more positive than that of the introspection and the time, and much less positive than that of the introspection and deflection. This militates considerably against any supposition that the objective criteria are significantly influenced by any mental factors independent of the introspection. In so far as these measures are measures of emotional response, they should be influenced together by the factors of the emotional response; and since they are not so affected together, but their correlations with the emotional grades are relatively independent, their relation to the emotional reaction does not seem to be influenced by extra-conscious mental factors to any important degree.[1]

Previous mention has been made of the phonograph as a source of emotional stimuli. The advantage lies in the greater constancy

[1] When, as occasionally happens, a low emotional grade attaches to both an increased deflection and a lengthened association time, this is best interpreted as the result of calling up a considerable body of rather vivid associative imagery, which lengthens the association time by increasing the difficulty of choice, and at the same time obscures the introspection of the emotional reaction. We can merely offer it as a matter of experience that less clear affects are apt to be considered less intense. One must remember also the possibility of suppression causing an underestimation of the emotional grade. In this way the association time, while of little value in itself as a measure of the affect, may often be useful in modifying the interpretation of the deflections.

of stimulus. It is effective enough in the individuals of musical perceptions, provided the instrument is of a good grade and carefully handled, and the records properly selected. The writers found the final trio of *Faust* the most effective of the records employed. Some subjects, unaware of the nature of the phenomenon, have observed the deflections while listening to the record, and discovered for themselves the relation of the movements of the light to the more stirring portions of the record.

The above recounted experiments indicate the most that can be expected of the method in its present evolution. The examination of the quantitative relationships of the deflections in the different experiments is sufficient to indicate how great are the variations in the susceptibility of the same individual at different times. This seems indeed, to be but slightly less than that between a number of different individuals. There are recorded occasional experiments in which the subject is absolutely refractory, *i. e.,* the electrical reactions are unmeasurably minute, or fail altogether. The greatest galvanometric activity observed by the writers in any individual is about ten times that prevailing in the experiments just described. No account has been taken of any galvanometric phenomenon but the principal reaction deflection; indeed, the very important question of the electrical reaction time has been practically disregarded because the apparatus is not of a type to lend itself to precise determinations on this point. A considerable opportunity for advance in the problem rests in the improved instruments and methods that are becoming available. For the present, it would be unwise to make absolute claims, but it may be reasonably asserted that as an objective criterion of emotional reaction, the electrical reflex appears distinctly superior to any analogous procedure as yet developed.

APPENDIX

Examination of Patients

Experiments were made with four cases of mental disease, two of whom were cases of catatonic stupor, one a stupor of undetermined nature, and one of senile dementia. The senile case, although able to answer simple questions, showed practically no deflections with iso-potential electrodes, when tested with a variety of stimuli. Graphophone records were played, questions were asked, substances with strong odors were held close to the nose, and a threat of a prick with a pin was made. Throughout all this series of stimuli, the deflections remained nearly constant, the ray of light moving slowly to and fro, but at no point showing abrupt changes such as are noted with ordinary subjects.

With a second case, one apparently of deep confusion, with total inaccessibility, slight deflections were noted, but most of these seemed associated with bodily activity, which it was difficult to prevent. Only a few stimuli were given, and little significant evidence was obtained.

The two cases of catatonic stupor showed some rather striking phenomena. In the first case,[1] the consciousness was fairly marked, and, although the patient could not be made to speak, he, nevertheless, seemed aware of his surroundings and inclined to resist the efforts to place his fingers in the electrodes. He was finally induced to comply long enough to enable the putting of a few questions and the repetition of two graphophone records. Although the patient showed no outward sign of hearing or understanding the questions, a definite deflection followed each one of them and the magnitude of the deflections appeared significant. Most of them varied between 2 and 13 mm.; one, however, which concerned a personal friend, was followed by a deflection of 49 mm. Considerable deflections occurred during the playing of the graphophone records, the readings varying from 85 mm. at the start to 108 mm. at the end. The second case of catatonic stupor was an admirable one for study. The patient showed no evidence whatever of consciousness, lying motionless in whatever position placed. The electrode tubes were placed at opposite sides of the bed and the middle fingers of the two hands

[1] This patient had been in the apparatus several times previously, with similar results, in experiments from the previous work of Wells and Cady.

allowed to lie motionless in the fluid. A current from a dry cell was used. No stimulus of any sort produced any visible outward response. With the galvanometer reduced to .01 of its sensitivity, only slight changes followed verbal stimuli, although a deflection of 12 mm. was produced by the touch of a cold metal key upon the forehead. The galvanometer was then shunted to .1 of its full sensitivity and questions were addressed relating to events in the patient's history, concerning which she had talked during an earlier stage of the disease. These were interspersed with sentences in the Gothic language, which were, of course, meaningless to the patient. Slight reactions followed nearly all the sentences, whether English or Gothic. In some cases, the reactions following questions of significance to the patient were no greater than those following Gothic sentences, but in certain instances, deflections of 18 mm. and in one case, 30 mm. followed questions of special significance. The touch of a cold key on the forehead caused a deflection of 31 mm.; the entrance of the nurse into the room caused a deflection of 12 mm.; the shutting of a door outside marking the approach of the examining physician caused a deflection of 15 mm.

The evidence furnished by these experiments tended to show that the failure of ordinary response in these cases of catatonic stupor resulted rather from inhibition of reaction than from failure to apprehend. They mark a contrast between these conditions and that of the senile patient, who although able to converse with a slight degree of intelligence, showed no evidence of affective reaction, and possibly also with that of the second named case, who showed no reaction of comprehension to questions that if understood could scarcely have failed to be of marked emotional import.

LITERATURE ON THE "PSYCHOGALVANIC REFLEX" AND ALLIED PHENOMENA

TARCHANOFF. Über die galvanischen Erscheinungen, etc. *Pflüger's Archiv*, XLVI., 46–56.

STICKER. Über Versuche einer objectiven Darstellung von Sensibilitätsstörungen. *Wiener klin. Rundschau*, XI., 497–501, 514–518.

SOMMER. Zur Messung der motorischen Begleiterscheinungen psychischer Zustände. *Beiträge z. psychiat. Klinik*, I., 157–164.

SOMMER U. FÜRSTENAU. Die elektrischen Vorgänge an der menschlichen Haut. *Klinik f. Psych. u. Nervös. Krankh.*, I., 113.

VERAGUTH. Das psychogalvanische Reflexphänomen. *Monatssch. f. Psychiat. u. Neurol.*, XXI., 387–425.

PETERSON & JUNG. Psycho-physical Investigations with the Galvanometer and Pneumograph in Normal and Insane Individuals. *Brain*, XXX., 153–218.

JUNG. On Psychophysical Relations of the Associative Experiment. *Jour. of Abnorm. Psychol.*, I., 249–257.

RICKSHER & JUNG. Further Investigations on the Galvanic Phenomenon and Respiration in Normal and Insane Individuals. *Jour. of Abnorm. Psychol.*, II., 189–217, and references.

BINSWANGER. Ueber das Verhalten des psychogalvanischen Phänomens beim Assoziationsexperiment. *Jour. f. Psychol. u. Neurol.*, X., 149–181; XI., 65–95, 133–153.

VERAGUTH. Le réflexe psychogalvanique. *Arch. de Psychol.*, VI., 162–163.

KNAUER. Kritische Bemerkungen zu O. Veraguth's Buch, "Das psychogalvanische Reflexphänomen." *Jour. f. Psychol. u. Neurol.*, XIV., 71–78.

SIDIS & KALMUS. The Study of Galvanometric Deflections, etc. *Psychol. Rev.*, XV., 391–396; XVI., 1–35.

SIDIS. The Nature and Causation of the Galvanic Phenomenon. *Psychol. Review*, XVII., 98–146.

STARCH. Mental Processes and Concomitant Galvanometric Changes. *Psychol. Review*, XVII., 19–36.

DUNLAP. Galvanometric Deflections with Electrodes applied to the Animal Body. *Psychol. Bull.*, VII., 174–177.

SIDIS. The Nature and Cause of the Galvanic Phenomenon. *Jour. of Abnorm. Psychol.*, V., 69–74.

SIDIS. The Galvanic Phenomenon. *Psychol. Bull.*, VII., 321–322.